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FOR

**METHOD AND APPARATUS FOR GRAPHING
MOTION OF COMPUTER AIDED DESIGN (CAD) GEOMETRY**

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METHOD AND APPARATUS FOR GRAPHING

MOTION OF COMPUTER AIDED DESIGN (CAD) GEOMETRY

FIELD OF INVENTION

- 5 The invention relates to the field of computer aided design (CAD). More specifically, the invention relates to graphing motion of CAD geometry.

BACKGROUND OF THE INVENTION

- 10 Computer aided design (CAD) programs have allowed users to design various parts in "virtual" space before the parts ever reach a manufacturing stage. As CAD programs have become more powerful, parts modeled in "virtual" space (i.e., CAD models) have become more true to life. For example, a complex machine, such as, a loader, (commonly seen loading and moving material with its bucket attached to the front) can now be fully designed and assembled in "virtual" space as CAD models, down to the smallest details.

- 15 Because of the costs associated with manufacturing complex machines, engineering design information regarding such machines is important to ascertain before manufacturing begins. Examples of engineering design information may include information regarding motion of the machine, loads and stresses on such components during the operation of the machine, and so forth. In order to determine these types of engineering design information, often times it is important to determine the motion of the machine and its components. For instance, angles and
- 20

ranges of motion can affect the design information of the machine, i.e., stresses and forces experienced by the machine and its components.

Determining the motion of a machine often times involves extensive geometry calculations on numerous components of the machine. Such calculations can be very time consuming and difficult as the complexity of the motion of the components increases, when, for instance, the motion is not restricted to a single plane but includes motion both up and down and side to side.

Once the geometry calculations are completed, the motion of the machines is often charted/graphed manually to visually represent the calculated motion.

However, the charted/graphed motion is only as good as the calculations. That is, a manual charting/graphing of extensive geometry calculations is prone to error.

Finally, once the motion of the machine is charted/graphed, engineering design information is manually calculated by ascertaining information from the manually charted/graphed motion. Each of these manual steps is time consuming and prone to error due to the extensive calculations.

BRIEF DESCRIPTION OF DRAWINGS

The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which the like references indicate similar elements and in which:

5 **FIGURE 1** illustrates a block diagram of one embodiment of a mechanical design application for facilitating charting/graphing motion of CAD models, in accordance with one embodiment of the invention;

10 **FIGURES 2A-2C** illustrate an exemplar-simplified assembly of CAD models of a mechanical design with corresponding constraint menus showing constraints for the assembly;

FIGURE 3 illustrates an exemplary CAD model upon which one embodiment of the invention may be practiced;

15 **FIGURE 4** illustrates an exemplary end user interface for facilitating automatic charting/graphing motion of CAD models, in accordance with one embodiment of the invention;

FIGURES 5A & 5B illustrate automatically generating and displaying a grid pattern at a selected center of motion based upon a range of motion, in accordance with one embodiment of the invention;

20 **FIGURE 6** illustrates adjustment of a grid pattern to ensure that the range of motion does not extend beyond the grid pattern, in accordance with one embodiment of the invention;

FIGURE 7 illustrates exemplary engineering design information determined from the automatic charting/graphing motion of CAD models practicing one embodiment of the invention;

FIGURE 8 illustrate the relevant operational flows of one embodiment of a motion analysis engine; and

FIGURE 9 illustrates one embodiment of a computer system suitable to be programmed with the mechanical design application of the invention.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various aspects of the invention will be described.

However, it will be apparent to those skilled in the art that the invention may be practiced with only some or all described aspects. For purposes of explanation,
5 specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the invention. However, it will also be apparent to one skilled in the art that the invention may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the invention.

10 Parts of the description will be presented in terms of operations performed by a computer system, using terms such as data, flags, bits, values, characters, strings, numbers and the like, consistent with the manner commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. As well understood by those skilled in the art, these quantities take the form of
15 electrical, magnetic, or optical signals capable of being stored, transferred, combined, and otherwise manipulated through mechanical and electrical components of the computer system, and the term computer system includes general purpose as well as special purpose data processing machines, systems, and the like, that are standalone, adjunct or embedded.

20 Various operations will be described as multiple discrete steps in turn, in a manner that is most helpful in understanding the invention. However, the order of description should not be construed as to imply that these operations are necessarily

order dependent. In particular, these operations need not be performed in the order of presentation.

In various embodiments of the invention, an improved way of charting/graphing motion of CAD models is facilitated. Additionally, from the charted/graphed motion, engineering design information may be determined. These and other advantages will be evident from the disclosure.

FIGURE 1 illustrates a block diagram of one embodiment of a mechanical design application for facilitating charting/graphing of motion of CAD models, in accordance with the invention. In **FIG. 1**, mechanical design application **100** includes an end user interface **102**, a design engine **104**, and a design database **106**. The design engine **104** includes, in particular, a motion determination engine **108**, in accordance with the invention. Together, the elements cooperate to facilitate charting/graphing of motion of CAD models, and, from the charted/graphed motion, determining of engineering design information.

In **FIG. 1**, the end user interface **102** operates to graphically display and receive input, from a user, of CAD models under the control of the design engine **104**. Also under the control of the design engine **104**, the design database **106** operates to store CAD model information for determining motions of various components of the CAD model. In particular, the motion determination engine **108** utilize various inputs to automatically chart/graph motion of CAD models, and, from the charted/graphed motion, determine engineering design information. Except for the teachings of the invention incorporated in the motion determination engine **108**, the mechanical design application **100** is intended to represent a broad range of

CAD software known in the art, including but not limited to Autodesk Inventor™, available from Autodesk, Inc. of San Rafael, California.

FIGURES 2A-2C illustrate an exemplar-simplified assembly of CAD models of a mechanical design with corresponding constraint menus showing constraints for the assembly. In **FIG. 2A**, a first CAD model, a body **210**, is assembled with a second CAD model, a handle **211**. As shown in **FIG. 2A**, the handle **211** is aligned with the body **210**, in particular, a handle hole **205** in the body **210**. As the two models **210** and **211** are assembled together, a user (not shown) inputs constraints for the assembly.

Constraints define relationships among CAD models making up an assembly. For example, as shown in **FIG. 2B**, a constraint menu **215** may include an assembly constraint tab **220** having constraints such as, but not limited to, mate **221**, angle **222**, tangent **223**, and insert **224**. These assembly constraints **221-224** define positions of the CAD models in the assembly relative to each other. Also included in the constraint menu **215** is a motion constraint tab **230** having constraints, such as, but not limited to, rotation **231**, rotation/translation **232**, forward motion **233**, reverse motion **234**, and limits of the motion **235**.

For the example shown in **FIG. 2A**, the constraints **221-224** and **231-235** may be selected to define the position and motion of the handle **211** relative to the body **210** about the handle hole **205**. Since the motion and position of the handle may be defined from its position in the handle hole **205**, in particular, along an axis of the handle hole **205**, the handle hole **205** may be defined as a center of motion for this

assembly. Once the user inputs all of these constraints, these constraints may be stored in the design database **106** of **FIG. 1**.

FIGURE 3 illustrates an exemplary CAD model upon which one embodiment of the invention may be practiced. Shown in **FIG. 3**, is a CAD model of a fully assembled machine **300**. In particular, the machine **300** includes a bucket **310**, a bucket arm **315** attached to the bucket **310** to manipulate the bucket **310**, several centers of motion **320-323** about which the bucket **310** and the bucket arm **315** may pivot during motion of the bucket **310**, the arm **315**, and wheels **340**. Additionally, a horizontal line **333** represents a level ground for the machine **300**.

Various components of the machine **300** may be individual CAD models, where each of the CAD models resides in separate CAD files. In order to assemble the machine **300**, each of the CAD models may be brought into an assembly CAD file, where each of the various components are assembled to one another. As previously described, assembling the machine **300** involves constraints inputted by the user. These constraints may include how the various components are to position and move relative to each other. The constraints of the machine **300** may be stored in the design database **106** of **FIG. 1**.

The constraints may include axial mating conditions. Axial mating conditions can designate that a component is to rotate relative to another component. As shown in **FIG. 3**, each of the centers of motion **320-323** may be associated with a location where the components are fit together utilizing assembly constraints **221-224** and motion constraints **231-235** (shown in **FIG. 2B & 2C**), i.e., pin joints **320**, **321**, and **322**, and an axle **323**.

Various aspects of the motion of the machine **300**, in particular, the bucket **310** and its bucket arm **315** are information desired by an engineer. For instance, an engineer may use the information to determine forces generated in the machine **300** and its various components. These forces are often times related to geometries of motion of the machine **300**. Geometries of motion help determine the direction and magnitudes of the forces in various components of the machine **300**.

Shown in **FIG. 3** is a side view of the machine **300**. However, since the CAD model of the machine **300** is three dimensional, centers of motion may be determined for other planes of motion, such as, but not limited to, a side-to-side motion when viewed from the top. For instance, components of the machine **300** may allow it to turn and bend around corners causing side-to-side motion. The center of motion for the side-to-side motion in the illustrated embodiment of the machine **300** may be the pin joint **360**.

FIGURE 4 illustrates an exemplary end user interface for facilitating automatic charting/graphing of motion of CAD models, in accordance with one embodiment of the invention. As shown in **FIG. 4**, a menu **400** is displayed for a user (not shown) to receive inputs for charting/graphing of the motion of the machine **300**.

Shown in **FIG. 4**, grid menu **400** includes various inputs for displaying a grid pattern. One of the inputs shown is a text entry window for a grid name **410**. The grid name **410** may be utilized to input various names for different aspects of motion of the machine **300**, such as, but not limited to, motion of the bucket **310** relative to an arm pin joint center of motion **320**. Various grid names may be stored in the

design database **106** for different motions relative to different components, and subsequently retrieved for display at a later time.

Another input may be a placement of an origin **420** of a grid pattern that is, a location where the grid pattern may be zero. The origin input **420** includes various
5 selections **421-424**. Cursor location selection **421** allows a user to place an origin of a grid pattern at any location by placing a cursor in a location on the screen and cursor selecting. Coordinate location selection **422** allows a user to place an origin of a grid pattern at an inputted coordinate location, such as, but not limited to, an x-axis location and a y-axis location. Centroid of assembly selection **423** automatically
10 generates and displays a grid pattern with its origin at a center of gravity of an assembly, i.e., center of gravity for the entire machine **300**. Entity proximity selection **424** allows a user to place an origin of a grid pattern by placing a cursor close to a geometry piece and cursor selecting the area. The geometry piece closest to the cursor selection is automatically selected as the origin of the grid
15 pattern. In alternate embodiments, any number of approaches can be used to identify an origin.

Another input may be a format **430** of a grid pattern, which includes the type of information a grid pattern displays, such as but not limited to, identifiers **431** and scales **433**, i.e., identifying markers or numbered scales, respectively. The identifier
20 selection **431** includes an increments input **432**, where various intervals represented by a grid pattern may be inputted, such as, but not limited to, 2-meter increments. The scale selection **433** also includes an increments input **434**, but also includes a selection for a type of scale **435**, i.e., metric or English units.

As will be described in further detail later, the limits of the grid pattern need not be inputted because the motion determination engine **108** determines a range of motion for the CAD models. However, as shown in **FIG. 4**, the user may input margins/extensions criteria **436**. The margins/extensions criteria **436** define the envelope within which a range of motion may be displayed. For example, if the user inputs one (1) unit as the margins and 1 unit for extensions criteria **436**, a range of motion displayed within the grid pattern may be within 1 unit of the limits of the grid pattern, i.e., the range of motion may be within 1 unit and extend beyond by 1 unit.

Once the various inputs of the grid menu **400** are filled, the inputs are utilized to automatically generate and display a grid pattern to facilitate charting/graphing motion of CAD models, in accordance with the invention.

FIGURES 5A & 5B illustrate automatically generating and displaying a grid pattern at a selected center of motion based upon a range of motion, in accordance with one embodiment of the invention. For the embodiment shown in **FIGS. 5A & 5B**, the origin input **420** is selected as entity proximity **424** and the grid format **430** is identifiers **431** (shown in **FIG. 4**). The increments input **432** is selected as one (1) unit increments, and the margins/extensions input **436** is entered as one (1) unit. Additionally, the assembly of the machine **300** has been simplified to illustrate this one embodiment, i.e., certain other components of the machine **300** are not visible.

Shown in **FIG. 5A**, a selection of a center of motion, bucket arm pin joint **320**, is received when a cursor **510** is utilized by a user (not shown) to select in proximity of the bucket arm pin joint **320**. Additionally, a selection of a component, a bucket arm **315** of the machine **300**, is received by another cursor selection. In response,

motion determination engine **108** (shown in **FIG. 1**) determines a range of motion **570** of the bucket arm **315**. The range of motion **570** may be determined from constraints associated with the bucket arm **315** about the bucket arm pin joint **320**. The constraints associated with the bucket arm **315** may be pre-stored by the user, as previously described.

Once the range of motion **570** is determined, another cursor selection for the placement of an origin **520** of a grid pattern is received. As shown in **FIG. 5A**, the user utilizes the cursor **510** and cursor selects the wheel hub **323** by cursor selecting in proximity to the wheel hub **323**. In response to the cursor selection for the placement of the origin **520**, the motion determination engine **108** generates and displays a grid pattern **550**. The range of motion **570** is automatically displayed on the grid pattern **550**. Shown in **FIGS. 5A & 5B**, the generated and displayed grid pattern **570** has identifiers **551** in increments of one.

In **FIG. 5A**, the grid pattern **550** is generated and displayed based upon the range of motion **570**, i.e., horizontal increments of 1 (0-5) **552** and vertical increments of 1 (0-6) **551**. Because the origin **520** is selected as the wheel hub **323**, the vertical baseline **554** and the horizontal baseline **553** (i.e., the zero line) of the grid pattern **550** intersect at the wheel hub **323**, i.e., the origin **520**.

Also shown in **FIG. 5A**, the range of motion **570** has a vertical margin of 1 unit at the top of the range **551**, a horizontal margin of 1 unit at the right side of the range **552**, and an extension of 1 unit beyond the horizontal baseline **553**.

Referring now to **FIG. 5B**, in one embodiment, the user may cursor select the origin **520** of the grid pattern **550** and move it with a single cursor selection to a new

location. As shown in **FIG. 5B**, the new location may be any location, such as, but not limited to, location visually behind the CAD model of the machine **300**. In response, the grid pattern **550** is displayed in the new location without adjustments to the grid pattern **550**.

5 In alternate embodiments, as the grid pattern is moved to new locations, the motion determination engine **108** adjusts the grid pattern **550** to ensure that the range of motion **570** is within its limits by generating and displaying an updated grid pattern for the new location. As previously alluded to, the range of motion **570** may extend beyond the limits of the grid pattern **550** if the user selects to allow for extensions, i.e., the user may establish new margins/extensions.

10 Additionally, in one embodiment, if an alternate component (i.e., a different component) associated with the previously selected center of motion is selected, a range of motion for the alternate component is determined based upon the previously selected center of motion. The grid pattern is automatically adjusted to ensure that the range of motion for the alternate component is displayed within limits of the grid pattern.

15 In one embodiment, if the constraints for the assembly are modified, i.e., range of motion modified, here again, the motion analysis engine **108** adjusts the grid pattern to ensure that the displayed range of motion of the component is within limits of the grid pattern.

As shown in **FIGS. 5A & 5B**, the side profile of the CAD model is utilized to determine range of motion for generating and displaying a grid pattern. However, the range of motion of the CAD model may be in any view because the CAD model

is a three dimensional model, as previously described. Additionally, more than a single grid pattern may be generated and displayed at any given time, and multiple grid patterns may be viewed in multiple views (i.e., planes, x-y, x-z, y-z, and so forth).

5 As a result, utilizing constraints associated with CAD models, charting/graphing of motion of CAD models is facilitated.

FIGURE 6 illustrates adjustment of a grid pattern to ensure that the range of motion does not extend beyond the grid pattern, in accordance with one embodiment of the invention. Shown in **FIG. 6** is a grid pattern **600** is generated and displayed as if the grid format input **430** was selected as scale **433** (shown in **FIG. 4**). Additionally, the scale input **433** may have the increments set as every one and a half meters (1.5) with units **435** of both metric and English. The margins/extensions input **436** may be 1 unit (i.e., 1.5 meter) for margins and zero (0) units for extensions (i.e., no extensions permitted beyond the limits of the grid pattern). Accordingly, the grid pattern **600** has a horizontal scale **601** and a vertical scale **603**. The horizontal and vertical scales **601 & 603** may show two types of units, such as, but not limited to, meter and feet.

As can be seen in **FIG. 6**, the grid pattern **600** has a horizontal base line (i.e., a horizontal zero) **610** located part way up the grid pattern **600**, while a vertical zero **620** is at an origin **615**. The grid pattern **600** is the result of an adjustment of the grid pattern **600** to ensure that ranges of motion **630 & 635** are within the limits of the grid pattern **600**. In **FIG. 6**, ranges of motion **630 & 635** of the bucket **310**, in particular, the articulation of the bucket **310** about pin joint **322** is determined.

Shown in **FIG. 6**, the articulation of the bucket **310** about the pin joint **322** has, for example, two components of motion, a horizontal component with a horizontal range **630**, and a vertical component with a vertical range **635**.

The two ranges of motion **630 & 635** may be determined from the constraints pre-stored for the bucket **310** about the pin joint **322**. As previously described, constraints provide parameters for the motion of the components of the machine **300**. Additionally, the horizontal range **630** and the vertical range **635** may be displayed with units describing the extent of the motion for each of the ranges of motion **630 & 635** along their respective scales **301 & 303**.

In **FIG. 6**, the user, utilizing a cursor **510**, has selected to establish the origin **420** as entity proximity **424** (shown in **FIG. 4**) with the entity selected as the level ground representation **333**. Since the entity selected, the level ground representation **333**, is effectively a horizontal line, the motion determination engine **108** may request another selection to establish a horizontal and vertical component of the origin. As shown in **FIG. 5**, the user has selected, again utilizing the cursor **510**, the pin joint **320** resulting in the origin **615**.

Shown in **FIG. 6**, the vertical range **635** extends beyond the horizontal base line **610**, and as a result, the grid pattern **600** is extended beyond the base line **610** to ensure that the vertical range of motion **635** does not extend beyond the grid pattern **600**. However, as previously illustrated in **FIGS. 5A & 5B**, the user may select to allow the range of motion to extend beyond the grid pattern **600**.

Shown in **FIG. 6**, the side profile of the CAD model is utilized to determine the range of motion for a particular component of the assembly. However, as previously

described, the range of the motion may be in any view because the assembly is a three dimensional CAD model. Additionally, more than a single grid pattern may be displayed at any given time, and multiple grid patterns may be viewed in multiple views (i.e., planes, x-y, x-z, y-z, and so forth).

5 In alternate embodiments, as the grid pattern is moved to new locations, the motion determination engine **108** adjusts the grid pattern **600** to ensure that the ranges of motion **630 & 635** are within predefined limits. As previously alluded to, the ranges of motion **630 & 635** may extend beyond the limits of the grid pattern **600** if the user selects to allow for extensions, i.e., the user may establish new
10 margins/extensions.

As a result, automatic charting/graphing motion of CAD models is facilitated.

FIGURE 7 illustrates exemplary engineering design information determined from the automatic charting/graphing of motion of CAD models practicing one embodiment of the invention. Shown in **FIG. 7** is an exemplary table **700** has
15 various engineering design information, which may be determined from automatic charting/graphing of motion on grid patterns, such as the grid patterns **550 & 600** (shown in **FIGS. 5 & 6**). The engineering design information of table **700** may be for an assembly, such as, but not limited to, the machine **300** of **FIG. 3**.

The table **700** may be automatically generated from ranges of motion
20 automatically displayed on the grid patterns **550 & 600**, in accordance with one embodiment of the invention. As shown in **FIG. 7**, engineering design information that may be determined from the grid patterns **550 & 600**, may be motion information, such as, but not limited to, a range for digging distance **710**, a range for

digging reach **711**, a range for level crowding distance **712**, and a range for digging depth **713**. Additionally shown in **FIG. 7**, engineering design information may also include force information, such as, but not limited to, crowding force **714** and breakout force **715**. The motion information is utilized to determine the force information **714 & 715** because the force information may depend on the motion information, in particular, angles, which may be determined from the motion information automatically displayed on the grid patterns **550 & 600**. Engineering design information **710-715** determined from the grid pattern **600** of **FIG. 6** may be in units of the scales **601 & 603** displayed as part of the grid pattern **600**. Even though the grid pattern **550** of **FIG. 5** does not have scales (i.e., selected format is identifiers), engineering design information may still be determined using a default scaling unit corresponding to the file in which the assembly is contained.

As a result, automatic charting/graphing of motion of CAD models is facilitated. Additionally, from the automatic charting/graphing of motion, engineering design information may be determined.

FIGURE 8 illustrate the relevant operational flows of one embodiment of the motion analysis engine **108** of **FIG. 1**. For the illustrated embodiment, motion analysis engine **108** is programmed in an event driven model, i.e., motion analysis engine **108** is designed to be executed in a system environment where various event notification services are available from the operating system. One example of such an operating system suitable for practicing the invention is the Windows® operating systems, available from Microsoft Corporation of Redmond, Washington. In

alternate embodiments, motion analysis engine **108** may be implemented in other programming approaches known in the art.

As shown in **FIG. 8**, a selection of a center of motion for an assembly of computer aided design (CAD) models of a mechanical design is received **810**.

5 Additionally, a selection of a component of the assembly associated with the selected center of motion is received **812**. In response to receiving the center of motion and the component associated with the selected center of motion, the motion analysis engine **108** determines a range of motion for the component based upon the selected center of motion **814**. As previously described, the range of motion
10 may be determined by retrieving pre-stored constraints associated with various components of the assembly.

Furthermore, the motion analysis engine **108** receives a selection of an origin for a grid pattern, and in response the motion analysis engine **108** automatically generates the grid pattern based upon the determined range of motion **816**. Once
15 the grid pattern is generated, the motion analysis engine **108** automatically displays the grid pattern at the selected center of motion **818**.

The received selections may be facilitated by a user utilizing a cursor to select the center of motion, the component, and the origin for the grid pattern.

As a result, automatic charting/graphing of motion of CAD models is
20 facilitated.

FIGURE 9 illustrates one embodiment of a computer system suitable to be programmed with the mechanical design application of the invention. As shown, for the illustrated embodiment, computer **900** includes processor **902**, processor bus

906, high performance I/O bus 910 and standard I/O bus 920. Processor bus 906, and high performance I/O bus 910 are bridged by host bridge 908, whereas I/O buses 910 and 920 are bridged by I/O bus bridge 912. Coupled to processor bus 906 is cache 904. Coupled to high performance I/O bus 910 are system memory 914 and video memory 916, against which video display 918 is coupled. Coupled to standard I/O bus 920 are disk drive 922, keyboard and pointing device 924, and communication interface 926.

These elements perform their conventional functions known in the art. In particular, disk drive 922 and system memory 914 are used to store permanent and working copies of the mechanical design system incorporated with the teachings of the invention. The permanent copy may be pre-loaded into disk drive 922 in factory, loaded from distribution medium 932, or down loaded from a remote distribution source (not shown). Distribution medium 932 may be a tape, a CD, and DVD or other storage medium of the like. The constitutions of these elements are known. Any one of a number implementations of these elements known in the art may be used to form computer system 900.

In general, those skilled in the art will recognize that the invention is not limited by the details described. Instead, the invention can be practiced with modifications and alterations within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of restrictive on the invention.

Thus, an improved way for automatically charting/graphing motion of CAD models is facilitated.